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Final Report

Side Impact Fixed-Pole Crash Testing of the NHTSA Modified Vehicle

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16. Abstract A series of car-to-fixed pole crash tests was performed. The test vehicles were 2-door Volkswagen Rabbits. Three crashes were performed to select a test condition which represented a serious-to-fatal chest injury producing highway accident. The fourth crash utilized a structurally modified Rabbit with 3 inches of side interior padding.		
This report documents the selection of the crash conditions and the acceleration results as measured on the vehicles and on the 2 dummy surrogates used for each test.		
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NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

TECHNICAL SUMMARY

CONTRACTOR National Highway Traffic Safety Administration Vehicle Research and Test Center	CONTRACT NUMBER SRL-92
REPORT TITLE Side Impact Fixed Pole Crash Testing of the NHTSA Modified Vehicle	REPORT DATE September 1985
REPORT AUTHOR(S) Donald T. Willke and Michael W. Monk	

This report describes testing and analysis performed to assess the performance of a modified vehicle in side impact crashes into a fixed rigid pole.

Highway accident data were analyzed to determine conditions which contributed to most of the serious-to-fatal thoracic injuries. It was found that pole/tree impacts at around 20 mph were predominant. A 12 inch diameter pole was fabricated and installed to the front of a concrete barrier. An impact angle of 45° was selected and the test speed was first set at 20 mph. The 45° tow angle was achieved by altering the wheel setting hardware, fixing all wheel angles to 45°. Two Volkswagen Rabbit crash tests were performed to finalize the impact point and test speed. A third crash was performed at the final conditions -- 25 mph with the pole intruding into the compartment just rearward of the driver's head. A maximum intrusion of 19.3 inches was observed. The estimated probability of a serious-to-fatal chest injury for a 41 year old occupant was 13%.

The modified vehicle (which had side structural modifications as well as side interior padding) was then crashed in the same conditions. The observed intrusion was 17.3 inches and the estimated injury probability was 0%.

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1.0 INTRODUCTION

This report deals with the car-to-rigid pole side impact crash tests that were performed for the Vehicle Research and Test Center (VRTC) at the Transportation Research Center of Ohio (TRCO) as part of project SRL-92. It contains a statement of the objectives and a brief background for this research as well as an explanation of the approach developed for these tests.

Four crash tests were performed. Three of these utilized baseline Volkswagen Rabbits while the fourth used a structurally modified Rabbit, containing additional door and rear inner quarter panel paddings. The results and observations from these tests are also included.

2.0 OBJECTIVES

There were two objectives for this investigation. The first was to assess baseline occupant safety in a side impact rigid pole test. The second was to determine the effect of structural and padding modifications on occupant safety under these same test conditions.

3.0 BACKGROUND

Considerable research has been performed investigating occupant responses in car-to-car side impacts. Much of this research has included the evaluation of various mitigation concepts for the side impact environment.

In particular, two such concepts were evaluated, using a Volkswagen Rabbit as the test vehicle. One of these was a stiffening of the side structure, the other was the use of additional interior door padding. These concepts were tested both separately and in combination to determine what effect, if any, each had on occupant responses. The results indicated that

near-side occupant thoracic responses could be reduced more than 30% through the combined use of these mitigation concepts.

This finding was important since 68% of serious to fatal injuries to non-ejected occupants of side damaged passenger cars involved in a non-rollover accident were caused from a collision with another passenger car. Similarly, 20% were caused from impacts with stationary objects such as trees (1). It therefore became useful to determine if the mitigation concepts developed for car-to-car side impacts would also benefit the occupants of single vehicles involved in side impacts with stationary objects.

The conditions for the baseline testing were derived from highway accident data. Accidents in which the left or right side of a vehicle impacted a fixed object causing serious to fatal injury to an occupant were examined. It was attempted to derive a single set of conditions representative of the largest number of such accidents. It was anticipated that considerable latitude in test conditions would be indicated by the accident data, and that two or three tests with baseline vehicles would be necessary to establish final test conditions.

Once the test conditions were established for the baseline vehicle, an identical test was to be run utilizing a modified vehicle. This would then give some indication as to the benefits received from the modifications in the single vehicle to fixed object test mode.

4.0 VEHICLE TO FIXED POLE TESTING

4.1 Initial Parameter Selection

Before conducting the crash tests, it was necessary to establish an initial set of test parameters. Two accident files, the National Crash Severity Study (NCSS) and the National Accident Sampling System (NASS), were used to find impact speed

and angle, location of initial contact, and fixed object geometry.

The data base for the determination of these parameters consisted of non-rollover accidents in which a non-ejected occupant sustained a serious to fatal injury ($AIS \geq 3$). The general area of damage was to be the right or left side, the struck vehicle was to be a passenger car, and the striking vehicle or object was to be a pole or a tree. This last filter was derived from the data earlier, since about two-thirds of the single vehicle accidents referenced in the previous chapter had a stationary object of a tree or a pole.

An examination of the combined accident files found 23 such cases where information was available on the size of the pole or tree. The result was an average diameter of 14.3 inches and a standard deviation on that average of 9.4 inches. A pole diameter of 12 inches was selected.

The two accident files were then looked at separately. From the NCSS file, the median change in velocity (Δv) was 20 mph. This was based on 38 cases. When the principle directions of force (PDF) were examined (59 cases), it was found that 32% were at 1 or 11 o'clock, 32% were at 2 or 10 o'clock, and 22% were at 3 or 9 o'clock. Finally, the median value for the leading edge of damage was 34 to 35 inches forward of the wheelbase center (50 cases). There were only 6, 16, and 6 cases, respectively, in the NASS file and therefore it was not used in the selection of these three parameters.

From the above information, an impact velocity of 20 mph was chosen. Also, since two-thirds of the PDF's were evenly divided between 30 and 60 degrees, an impact angle of 45 degrees was selected. Finally, the location of the leading edge of damage was chosen as 35 inches forward of the wheelbase center.

4.2 Procedure/Hardware

In order to meet the parameters listed in the previous section in the conduct of these crash tests, it was necessary to build special hardware. First, a rigid pole was constructed from steel tubing with an outer diameter of 12 inches and a wall thickness of 3/8 of an inch. This pole, filled with concrete, was mounted to the face of the immovable barrier wall at the TRCO (see figure 4.1). Four 50,000 pound load cells, two at the top of the pole, two at the base, were mounted such that the total force exerted on the pole in the direction of impact could be measured. The entire pole structure could be adjusted along the barrier wall so that impact location on the car could be changed.

To achieve an impact angle of 45° , a decision was made to turn all four wheels of the car, enabling it to roll at this angle (see figure 4.2). This was done to the front wheels by simply removing the tie rods, pivoting the wheels, and fastening them at the desired angle. Since the wheel wells for the rear tires would not allow this much movement, fixtures were constructed which extended the rear axle. The tires were then mounted on these fixtures at 45° . The above adjustments were made with the vehicle ballasted at test weight. If this was not done, wheel alignments would change when the weight was added.

In the performance of these crash tests, it was necessary to tow the car through its center of gravity to insure proper tracking. For this reason, the impact location on the car could only be changed by moving the pole from side to side along the barrier wall. A plane, normal to the ground and parallel to the direction of tow, was projected from the forward edge of the pole to the car. The line at which this plane intersected the side of the car was defined to be the impact location, estimating the leading edge of damage. The location of the actual initial contact was about 2 1/2" rearward of this along the side of the car due to the curvature of the pole and angle of impact.

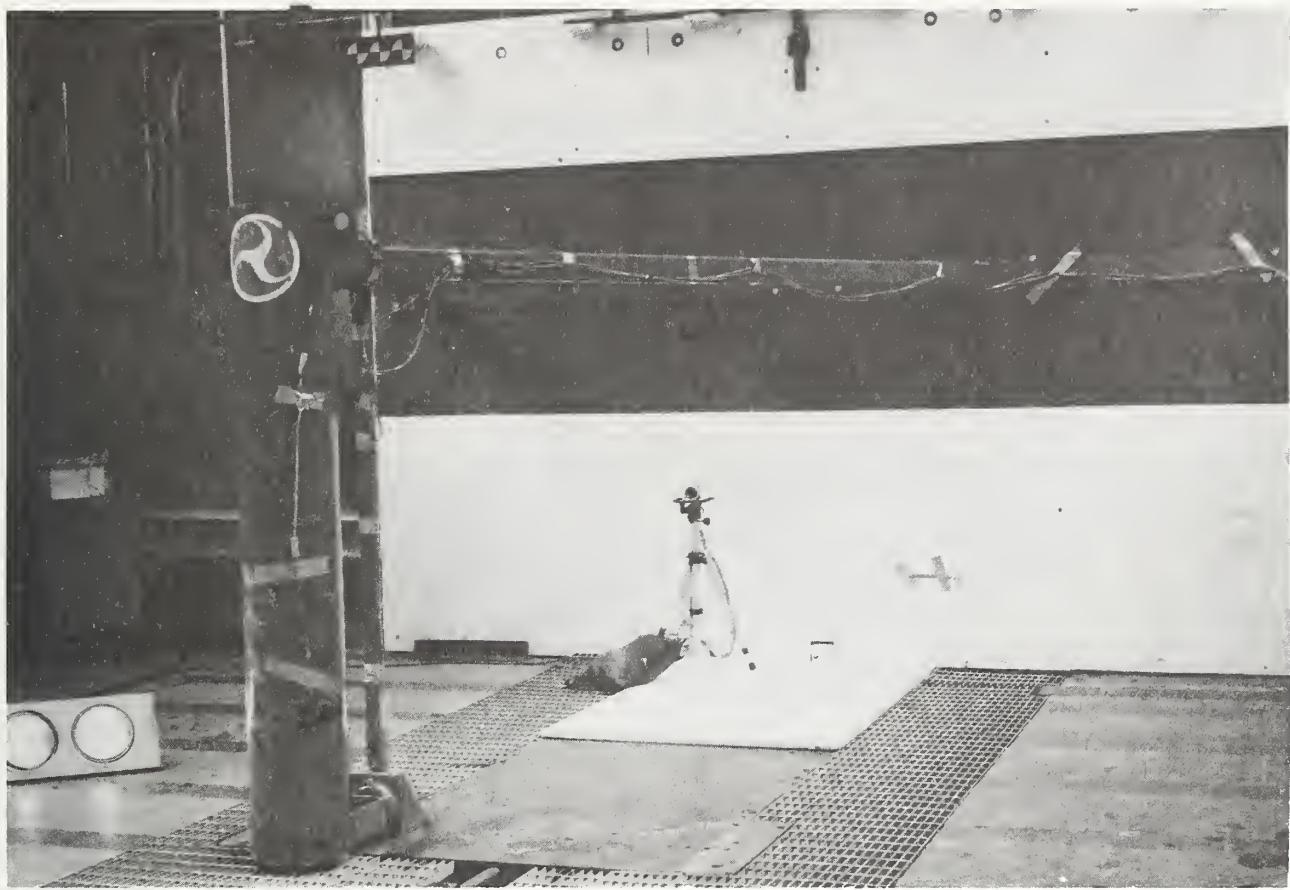


FIGURE 4.1 -- Overview of Pole-Test Hardware

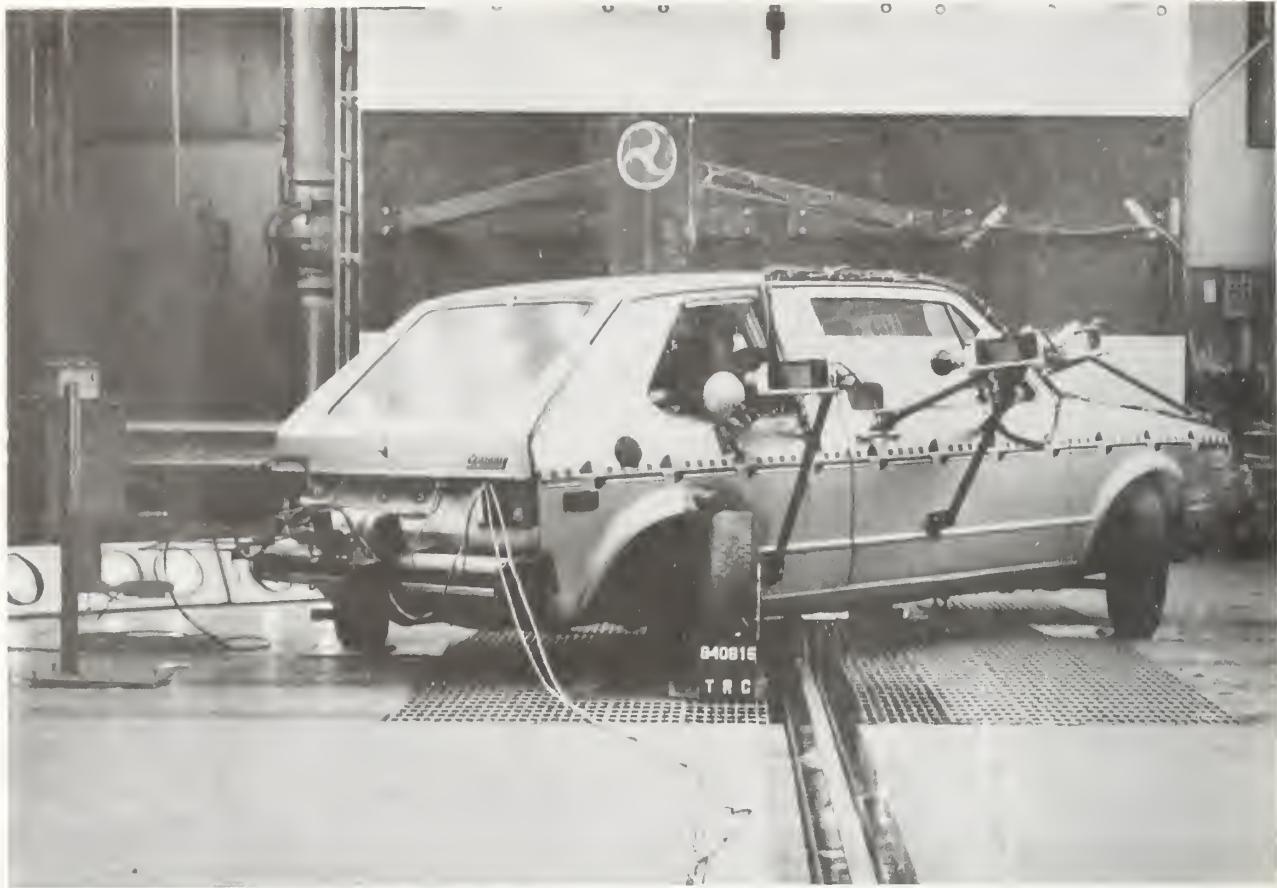


FIGURE 4.2 -- Vehicle Modifications for Angled Towing

4.3 Data Analysis and Instrumentation

As mentioned in the previous section, four 50,000 pound load cells were used to measure the force exerted on the pole in the direction of impact. Two of these were mounted at the top of the pole, two at the base.

In addition to this force data, information was collected from several other sources. First of all, two side impact dummies (SID's) were seated in the vehicle at the driver and left rear passenger positions. The thorax of each of these was instrumented with twelve accelerometers and a linear displacement potentiometer. The accelerometers were located on the left upper and left lower ribs and the upper and lower spine. Each location contained two lateral accelerometers and each of the spinal locations also included a vertical and a longitudinal accelerometer. The vehicle was taken to be the frame of reference, with longitudinal being fore to aft and lateral being side to side. The displacement potentiometer in each SID measured the relative deflection between the ribcage and the spine.

Three accelerometers mounted in a triaxial configuration were located at each of three locations on the vehicle. These were the right front and right rear sills as well as the rear deck (behind the back seat). In addition, five lateral accelerometers were placed on the left door and one on each of the left front and left rear sills. Finally, one longitudinal accelerometer was mounted on the trunk floor of the vehicle.

All of the data were digitized through a filter having cutoff and stopband frequencies of 1650 and 5214 Hz. This was the extent of the filtering for the six head accelerations, the two rib to spine deflections, and the four pole forces. The vehicle accelerations were additionally filtered using a infinite

impulse response (IIR) filter with cutoff and stopband frequencies of 100 and 316 Hz. The pelvic accelerations were additionally filtered using a 300/950 Hz IIR filter.

A more complex data processing routine was used on the thoracic accelerations. First a 300/950 Hz IIR filter was used. The data were then subsampled at 1600 Hz and refiltered using the HSRI finite impulse response (FIR) filter.

The probability of injury was then calculated using the peak rib and spinal accelerations. The maximum of the peak upper rib and the peak lower rib accelerations was used along with that of the lower spine to calculate the probability of receiving AIS 3, 4, and 5 injuries (1)*. In the referenced study, the estimation of probability of injury was found to be a function of acceleration response and occupant age. This was done for both the driver and passenger dummy responses using assumed occupant ages of 23 and 41. This first age is the median age for all injured occupants while the second is the median age for occupants receiving serious to fatal injuries.

5.0 RESULTS

The first crash test was performed using the parameters which were as near as possible to those outlined in the previous chapter. These were an impact speed of 20 mph, an impact location of 35" forward of the wheelbase center, and an impact angle of 45°. The actual speed was 20.0 mph and the actual location was 34.5". Table 5.1 lists the dummy responses and pole forces, while table 5.2 lists the probabilities of thoracic injury for this test.

Since the pole impacted near the A-pillar, the thorax of the driver dummy struck the soft, unbacked inner door. In addition,

*Number in parentheses designates reference at end of paper.

the latch of this door opened (an unexpected structural response) only a few milliseconds after pole to door contact, further softening the surface struck by the thorax. The responses indicated a very low probability of a severe injury, hence a repeat of this test using the proposed mitigation concepts could not possibly show a significant reduction in injury potential.

An alternate set of conditions within the latitude of the accident data was sought which would result in the desired range of injury response. Shifting the impact point rearward was selected. There was concern, though, that if it was moved such that the pole would contact the thorax directly through the door, the head would hit the pole violently. Since the mitigation concepts to be explored in these tests were for the thorax only, this was an undesirable condition.

A new impact location was set at 29" forward of the wheel-base center for the second test. The vehicle did not track correctly, though, resulting in an actual location of 26.5". The actual speed was 20.1 mph. As tables 5.1 and 5.2 indicate, the thoracic responses increased, but were still quite low. On the otherhand, the driver's head impacted the pole, resulting in a very high HIC value.

At this point several accident cases were reviewed to determine why head contacts with poles or trees were not occurring with appreciable frequency in the accident environment. Two situations seemed to emerge from the highway data. The first was the tendency for poles to lean away from the occupant when impacted, such that the head did not reach the adjacent pole. The second was that some cases had an impact point just behind the occupant seated position but induced structural damage was used in coding a leading edge of damage further forward. The second situation was the only one possible to simulate with the VRTC pole.

TABLE 5.1

Fixed Pole Crash Tests - Peak Dummy Responses

DRIVER	Pole #1 35"	Pole #2 26"	Pole #3 6.5"	Pole #4 modified
Up. Rib	38.2	59.7	83.5	50.8
Lo. Rib	37.3	54.3	57.5	56.9
Up. Spine	27.5	60.4	67.0	63.7
Lo. Spine	41.3	64.8	85.5	73.0
Pelvis	61.2	117.2	67.0	55.2
HIC	977	2945*	226	132
<hr/>				
Passenger				
Up. Rib	20.0	34.3	37.6	41.8
Lo. Rib	15.4	30.1	47.2	41.2
Up. Spine	24.2	31.4	50.3	35.1
Lo. Spine	16.8	23.8	48.1	36.6
Pelvis	10.0	20.0	127.1	76.3
HIC	151	239	552	512
<hr/>				
Up. Pole Force	7783	7589	8477	11,773
Lo. Pole Force	14,914	17,665	34,656	37,068

* Actual HIC was probably much higher since the accelerometer values were clipped due to the extremely hard hit.

TABLE 5.2

Fixed Pole Crash Tests - Probability of Thoracic Injury
AIS > n

DRIVER		Pole #1 35"	Pole #2 26"	Pole #3 6.5"	Pole #4 modified
Age	n				
23	3	1%	5%	17%	6%
	4	0	0	0	0
	5	0	0	0	0
41	3	9%	29%	57%	34%
	4	0	0	13%	0
	5	0	0	4%	0
PASSENGER					
23	3	0	0	1%	1%
	4	0	0	0	0
	5	0	0	0	0
41	3	2%	4%	14%	8%
	4	0	0	0	0
	5	0	0	0	0

It was then judged that the desired loading on the driver's chest accompanied by minimal loading on the head could be achieved by choosing an impact point a small distance behind the driver dummy. Assuming that the dummy's head continued to move in the direction of impact until it reached the pole, an impact location of 6.5" forward of the wheelbase center would result in the back of the head just grazing the forward edge of the pole. An impact location of 6.5" forward of the wheelbase center was therefore selected (see figure 5.1). The impact speed was also raised to 25 mph.

The actual impact location was 6.5" forward of the wheelbase center, while the actual speed was 24.9 mph. As intended, the driver's head just grazed the pole resulting in a low value for HIC. As tables 5.1 and 5.2 indicate, the driver dummy's thoracic responses were notably higher than those of the previous tests. It was judged that they were within the range of injury selected for simulation from the accident data.

Figure 5.2 shows the damage to the vehicle used in this test. A maximum intrusion measurement of 19.3" was taken at the mid-door height, 24" rearward of the impact location.

The fourth test repeated the test conditions of the third using a VW Rabbit that had been structurally modified and had an additional inner door padding. When an impact location was selected such that the back of the driver dummy's head would just graze the forward edge of the pole, it was found to be 9" forward of the wheelbase center. The difference between this and the previous test was believed to be due to the differences between the early model modified Rabbit used for this test and the later models used in the first three tests. It was judged that the position of the pole relative to the dummy seating position was more crucial than that relative to the wheelbase center, so an impact location of 9" was chosen (see figure 5.3). Once again, impact speed was to be 25 mph.

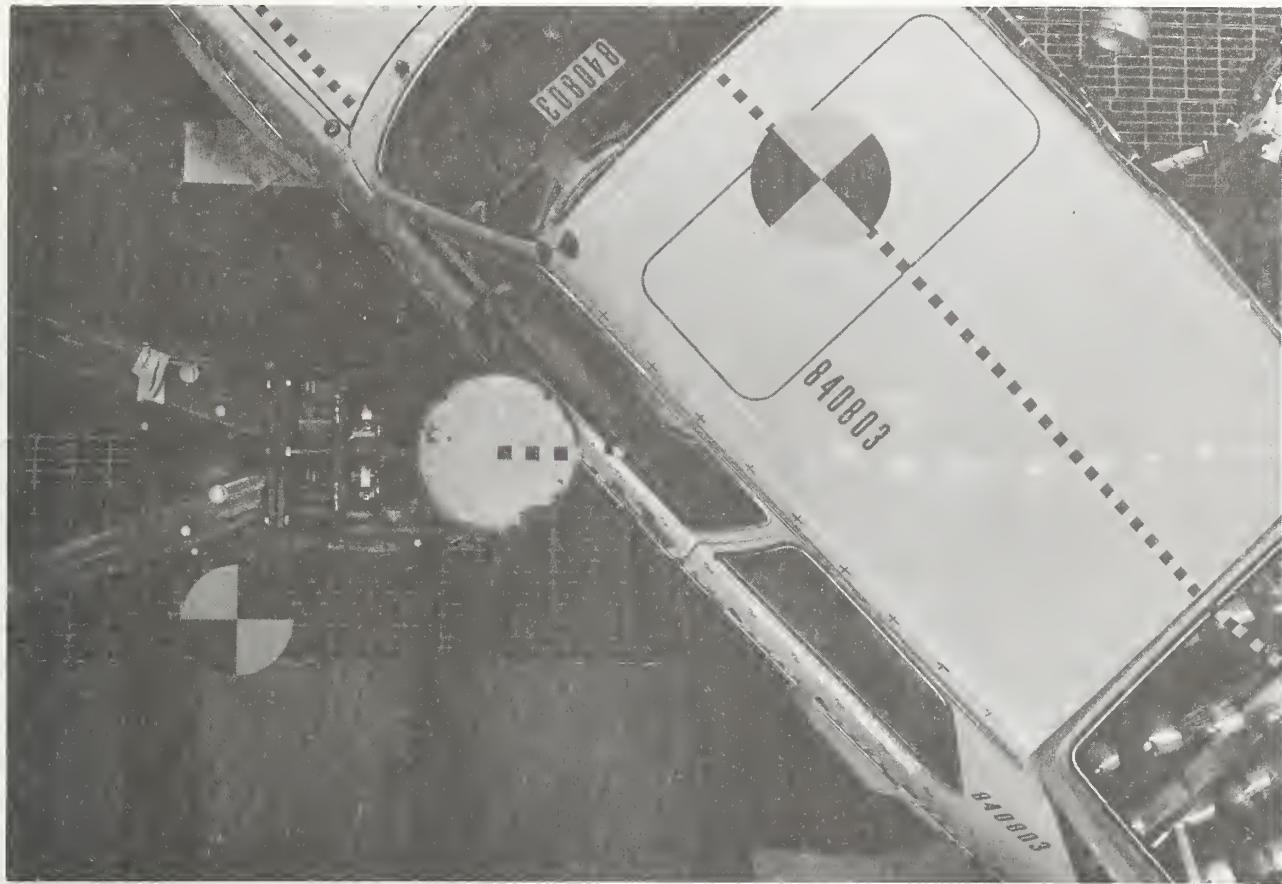


FIGURE 5.1 -- Pre-Test Impact Orientation
of Pole and Baseline Rabbit



FIGURE 5.2 -- Post-Test Damage of Baseline Rabbit



**FIGURE 5.3 - Pre-Test Impact Orientation
of Pole and Modified Rabbit**

Actual impact location was 9.0" forward of the wheelbase center and actual speed was 25.0 mph. As before, the head just grazed the forward edge of the pole resulting in a low value for HIC. As indicated in tables 5.1 and 5.2, the thoracic responses were lower than those of the previous test.

Figure 5.4 shows the damage to the vehicle used in this test. A maximum intrusion measurement of 17.3" was taken at the mid-door height, 12" rearward of the impact location.

The contractor for these tests (TRCO) has prepared and submitted reports for each of the four tests outlined here. These test reports are available if more detailed data are required. All tests were done as part of project SRL-92 and the test numbers are as follows:

Test #1 - 840629

Test #2 - 840706

Test #3 - 840803

Test #4 - 840816

6.0 OBSERVATIONS

The thoracic mitigation concepts extensively tested in the car-to-car crash environment were effective in reducing the thoracic injury potential in a single car-to-fixed pole crash test.

Two crash tests were performed in which VW Rabbits impacted a twelve inch diameter pole at an angle of 45 degrees and a velocity of 25 mph. The impact locations, relative to the driver dummy seating position, were also identical. One of these vehicles was a baseline Rabbit while the other was a structurally modified Rabbit containing additional interior door padding.



FIGURE 5.4 -- Post-Test Damage of Modified Rabbit

The peak lateral dummy responses from table 5.1 were generally lower in the modified car test than they were in the comparable baseline car test. For the driver, peak upper rib accelerations were lowered from 83.5 to 50.8 g's (39%), while lower rib responses went from 57.5 to 56.9 g's (1%). Also for the driver, upper spine readings decreased from 67.0 to 63.7 g's (5%), while those of the lower spine went from 85.5 to 73.0 g's (15%). Driver pelvic accelerations dropped from 67.0 to 55.2 g's (18%). It should be noted that the accuracy of the accelerometers used in these tests was $\pm 5\%$. Figures 6.1 through 6.5 are overlay plots of these responses.

The baseline vehicle test results indicated that a 41 year old driver had a 57% chance of receiving an AIS 3 or greater injury, a 13% chance of an AIS 4 or greater injury, and a 4% chance of an AIS 5 or greater injury. The modified vehicle test results indicated a 34% chance of receiving an AIS 3 or greater injury and no chance of receiving a more severe injury (see table 5.2). This is a reduction of 23% in the probability of receiving a serious injury and an elimination of the chance of receiving a life-threatening injury.

The observation noted above was made based on only one set of crash tests and therefore should not be considered conclusive.

REFERENCES

- (1) "Development of Dummy Injury Index for NHTSA's Thoracic Side Impact Protection Research Program"; R.H. Eppinger, J.H. Marcus, R.M. Morgan; Government/Industry Meeting, Washington D.C., 1984; SAE paper no. 840885.

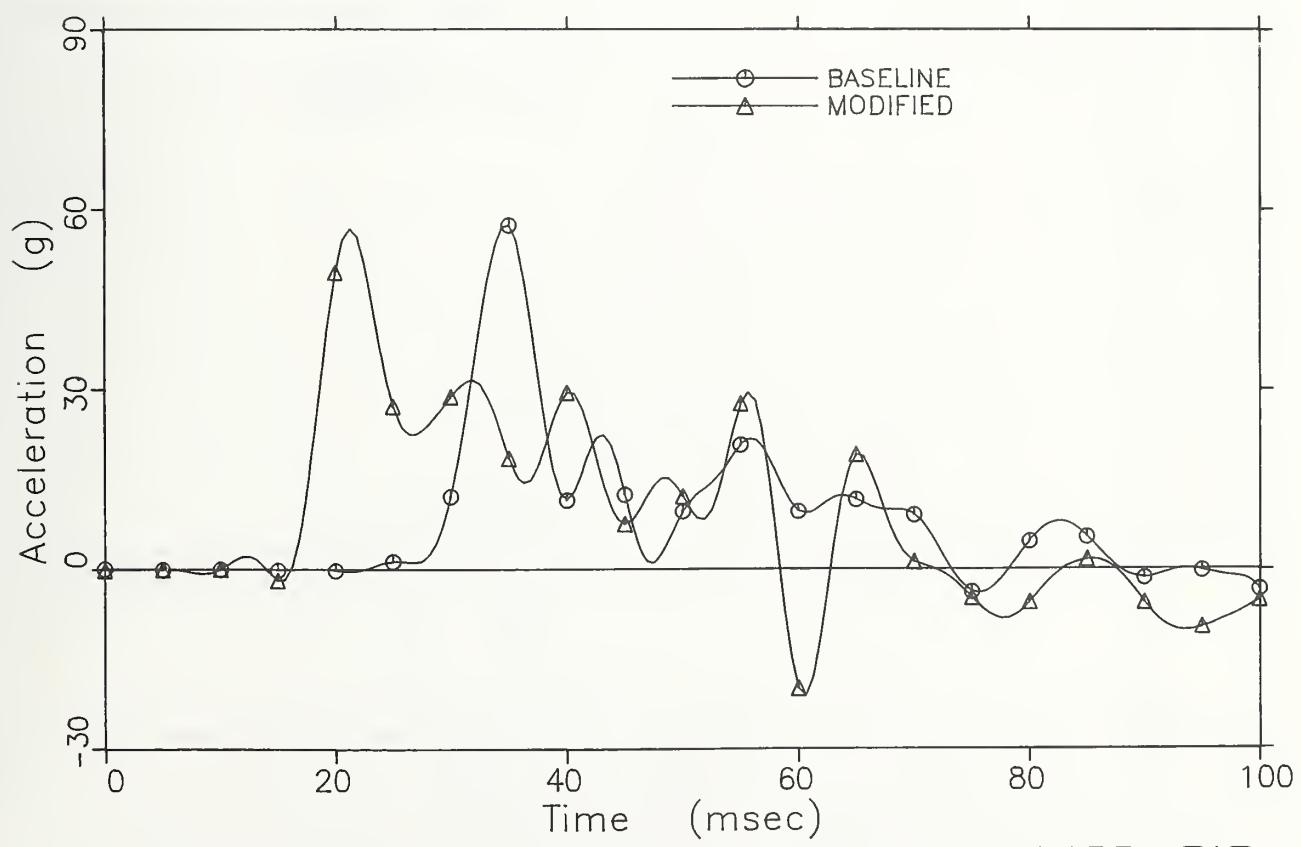
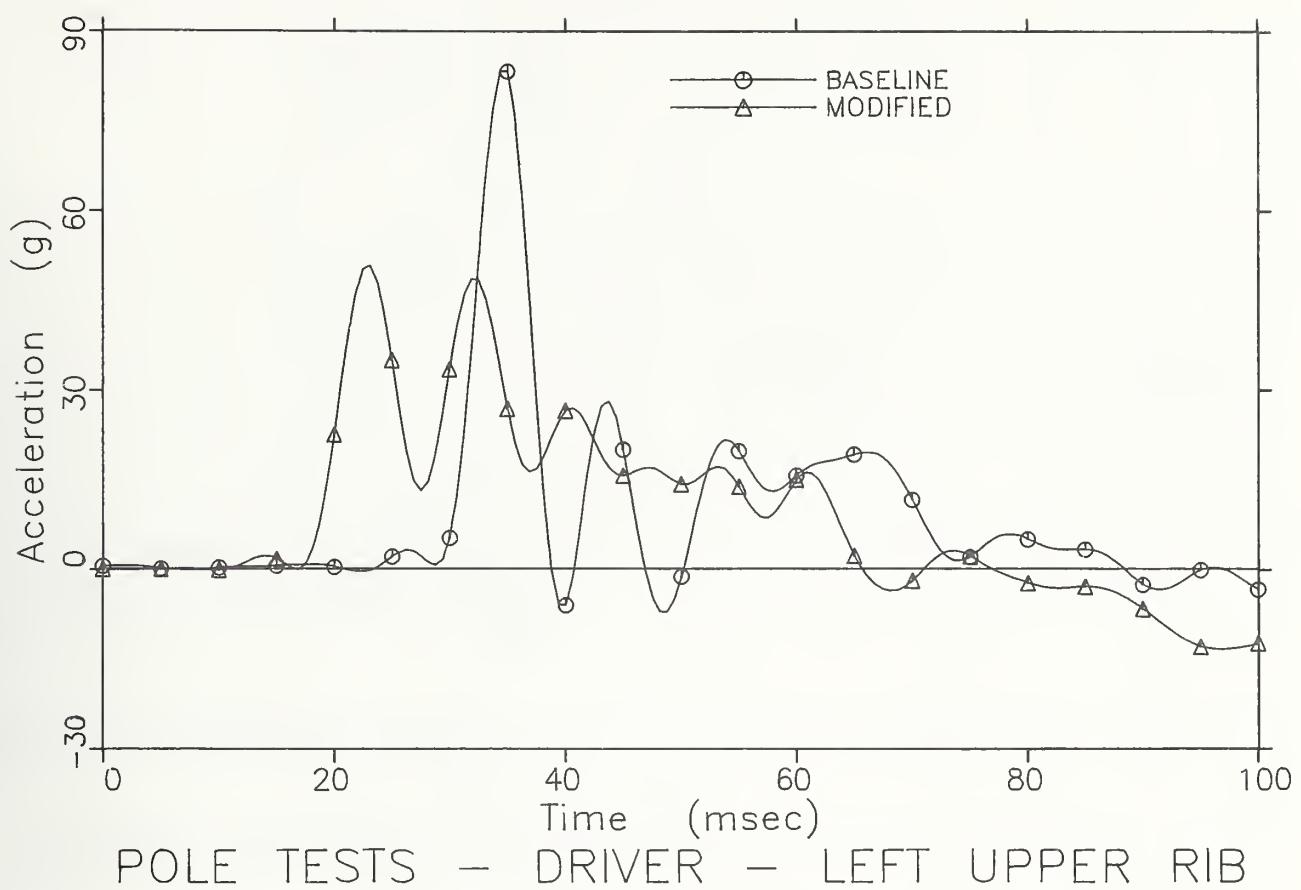
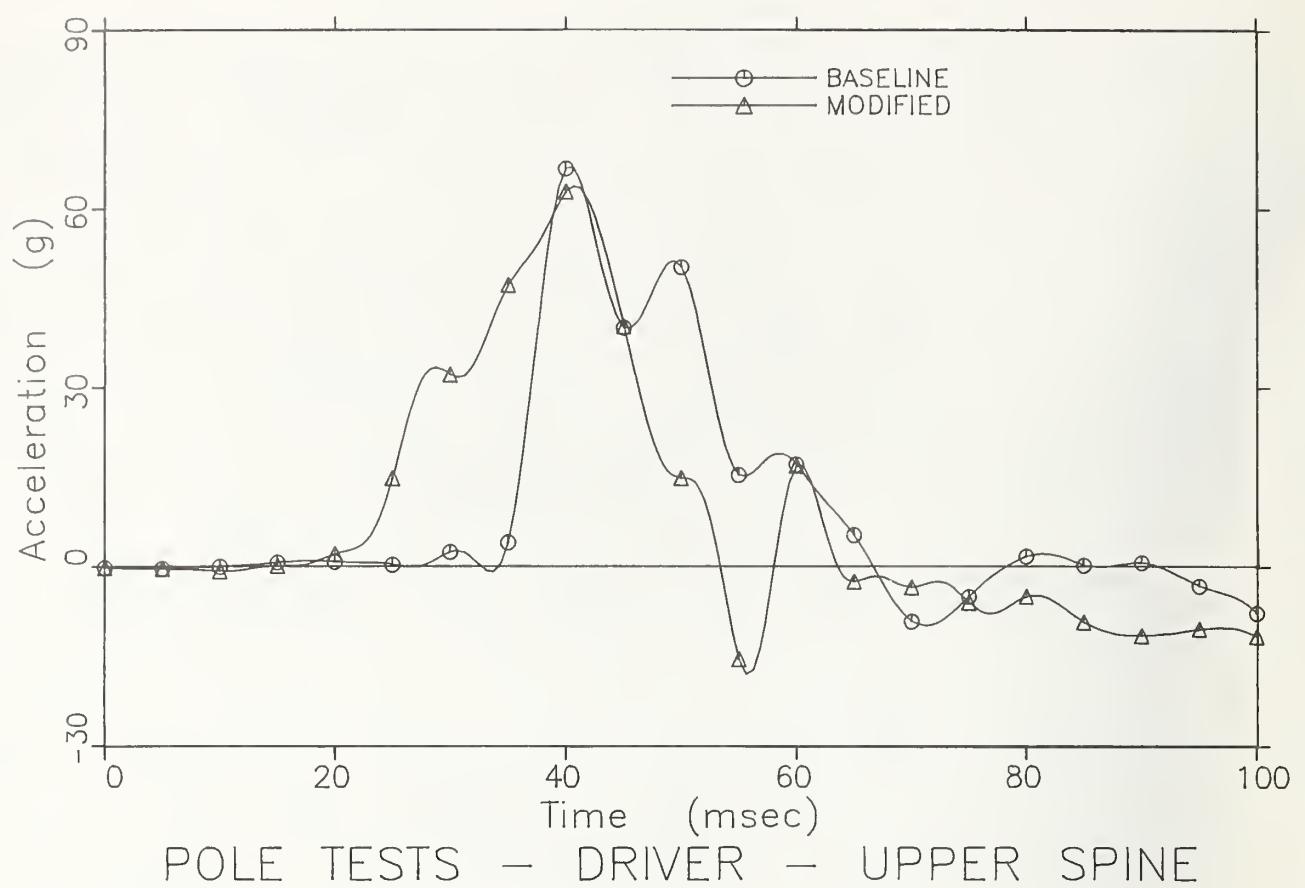
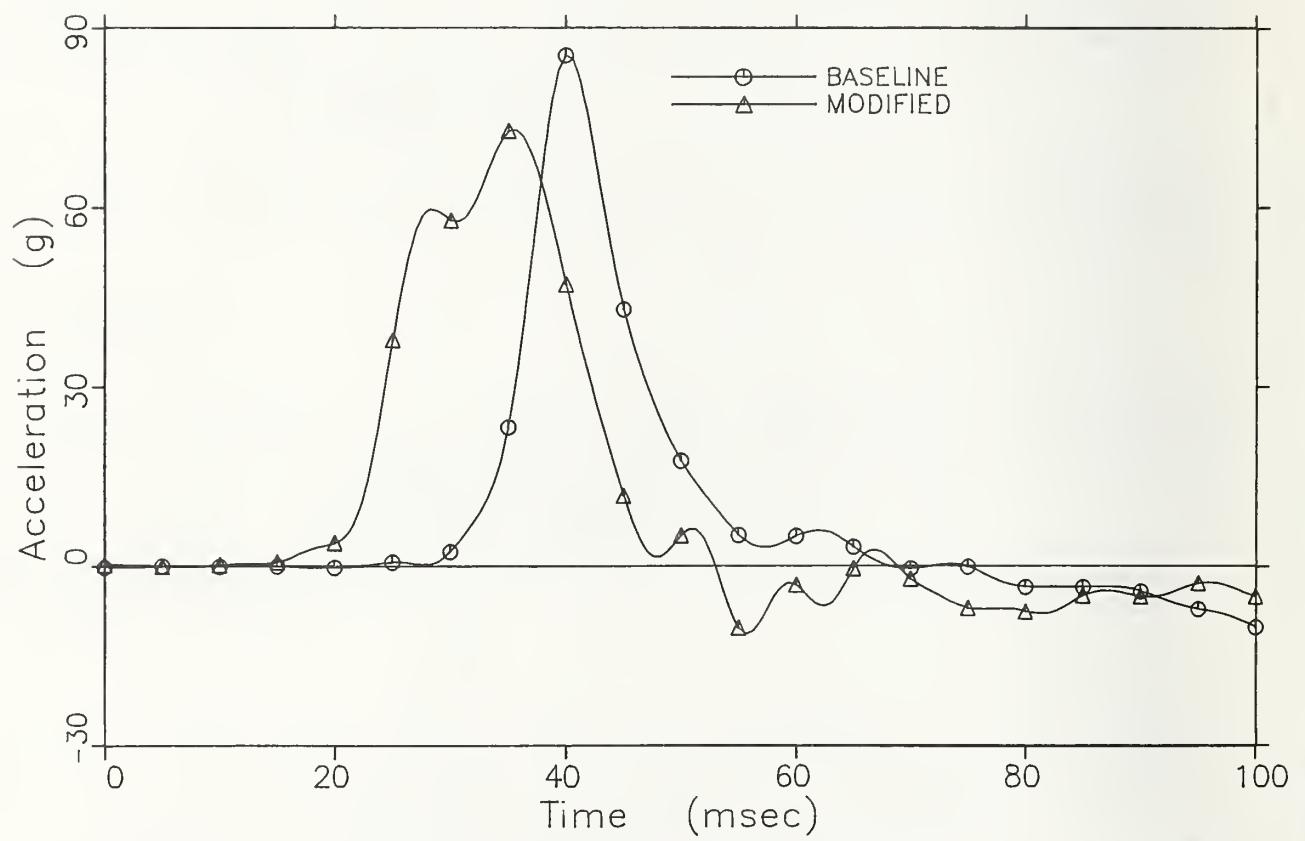


FIGURE 6.1 -- Comparisons of Driver Rib Acceleration Responses

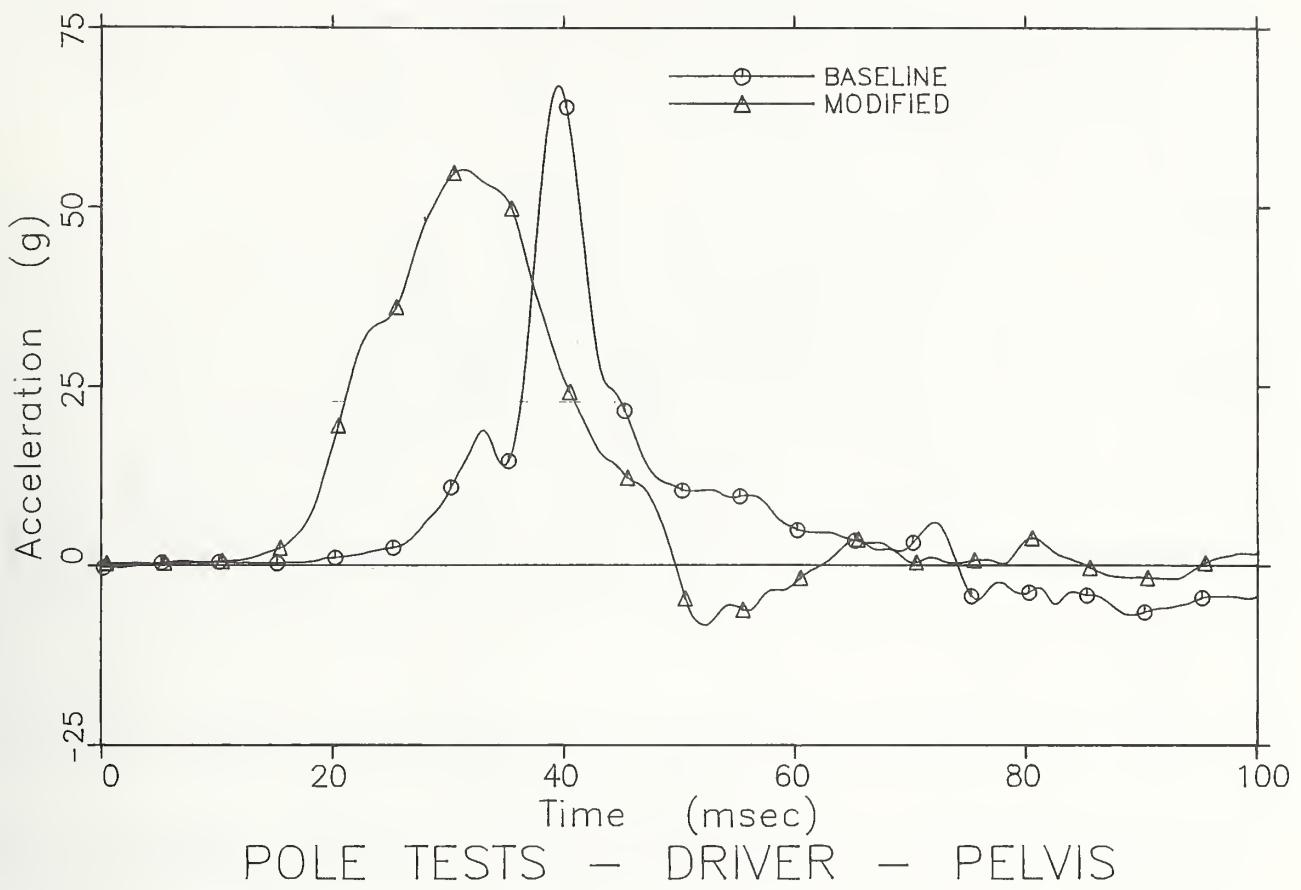


POLE TESTS — DRIVER — UPPER SPINE

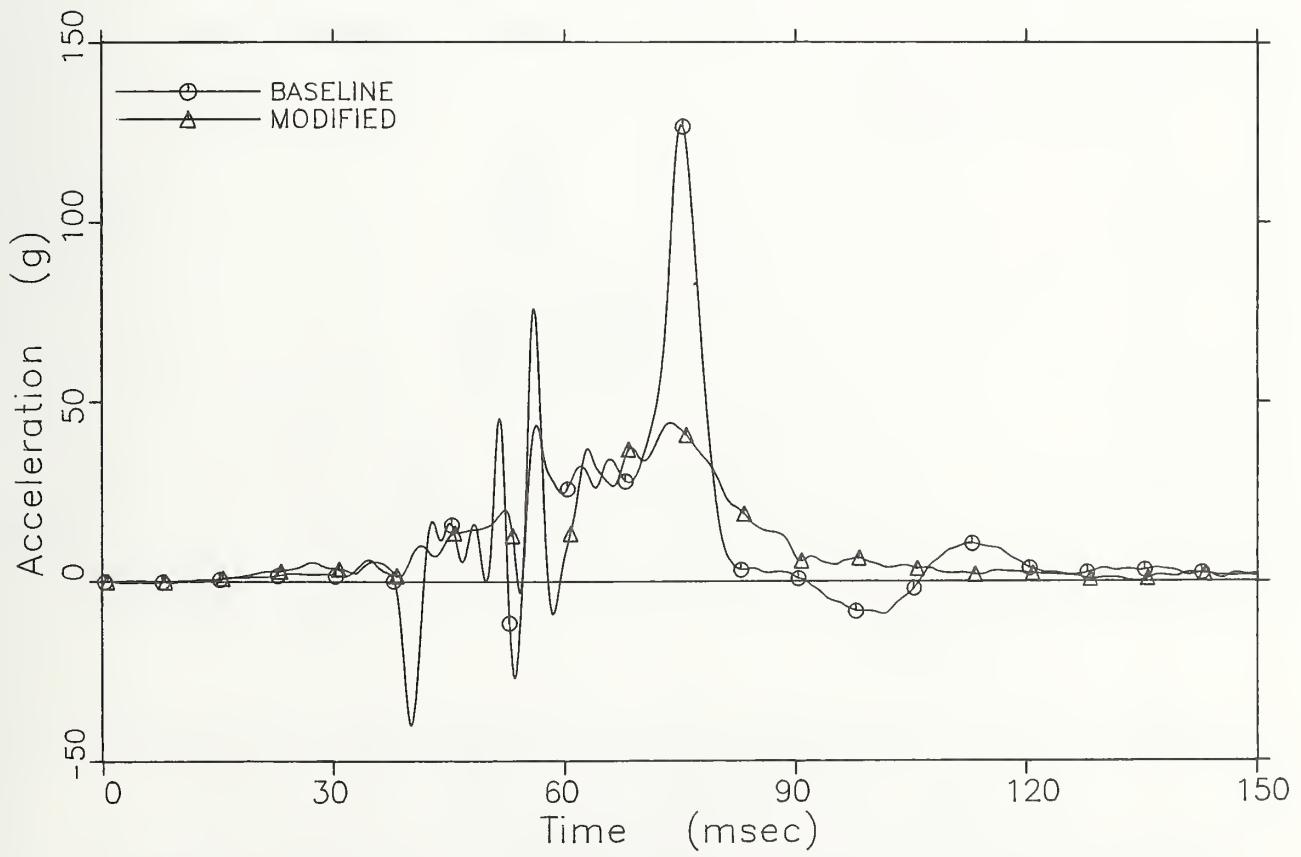


POLE TESTS — DRIVER — LOWER SPINE

FIGURE 6.2 -- Comparisons of Driver Spinal Acceleration Responses

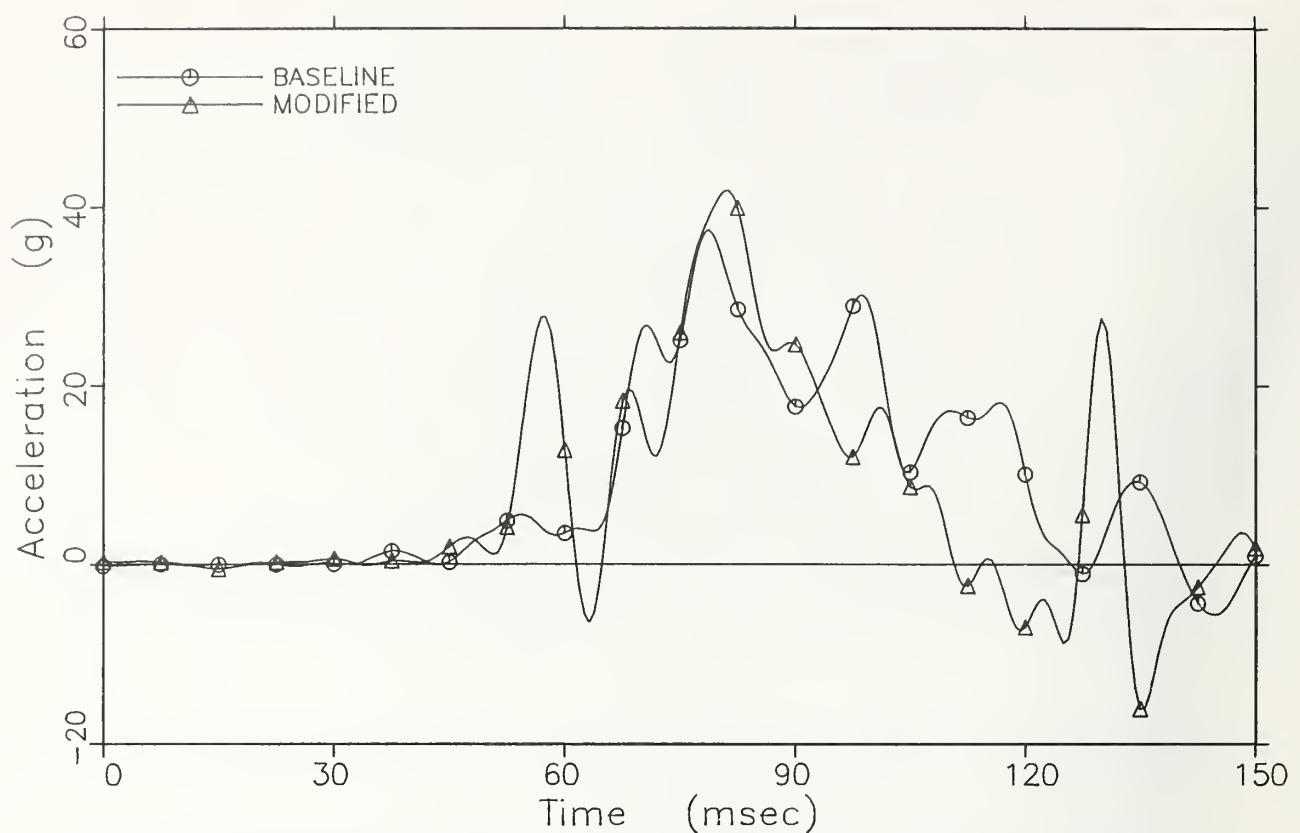


POLE TESTS — DRIVER — PELVIS

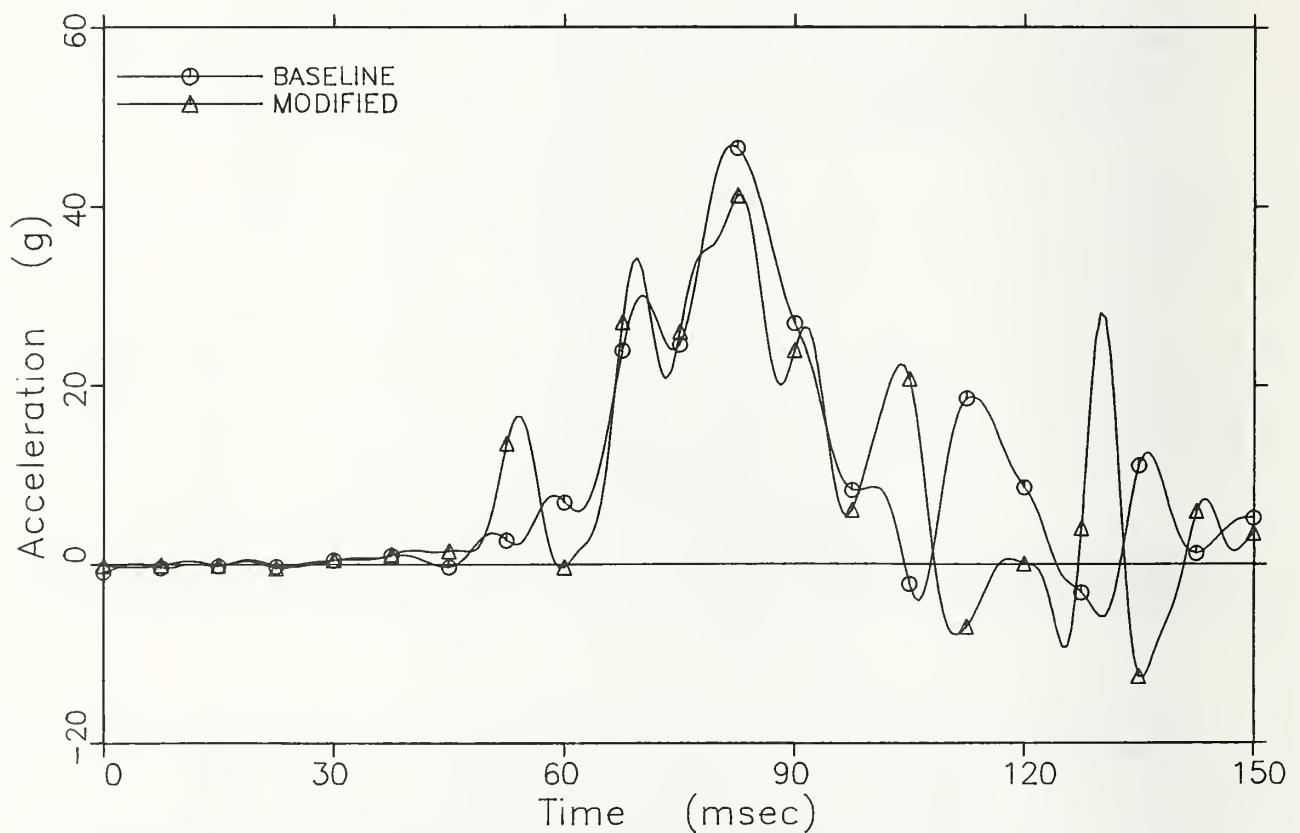


POLE TESTS — PASSENGER — PELVIS

FIGURE 6.3 -- Comparisons of Driver and Passenger Spinal Acceleration Responses

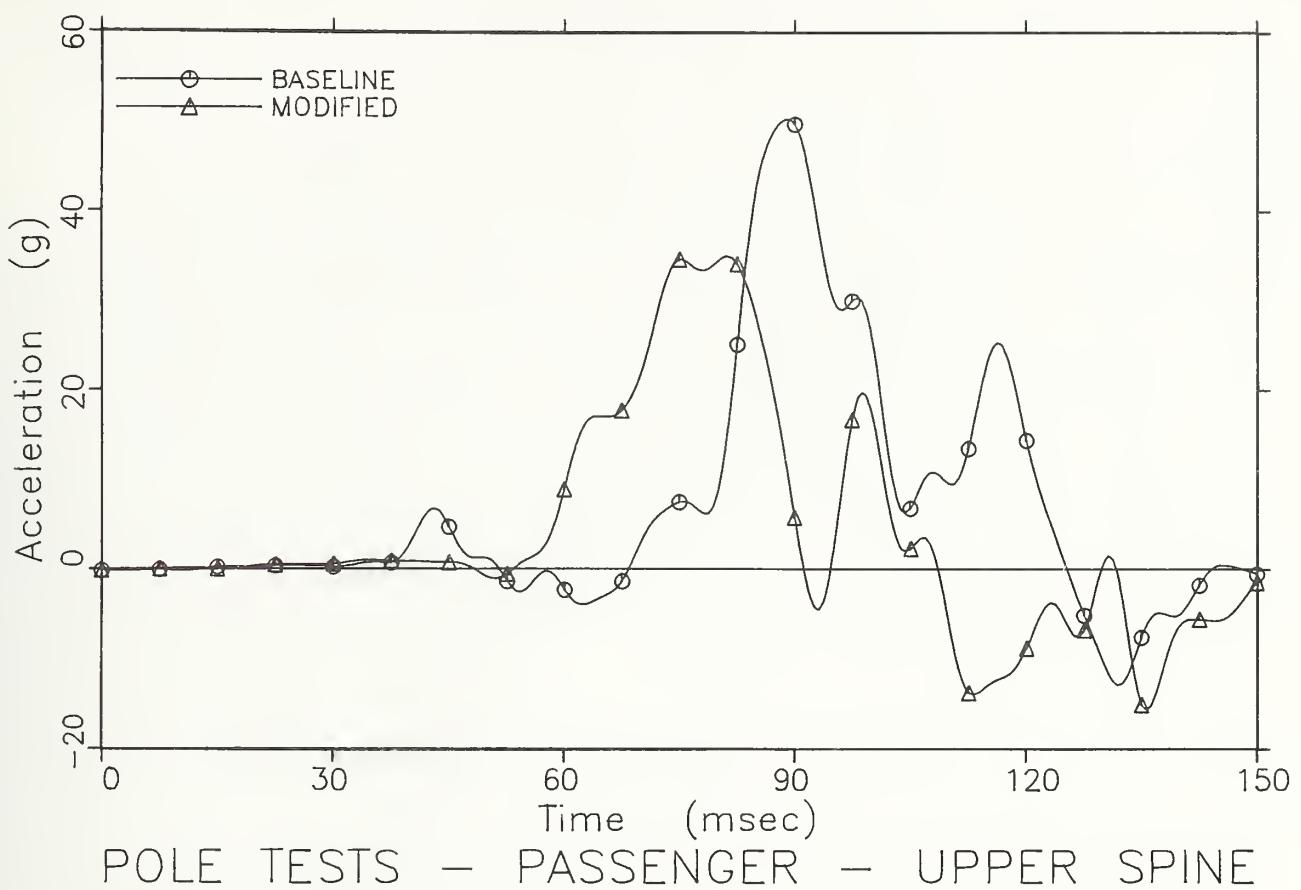


POLE TESTS - PASSENGER - LEFT UPPER RIB

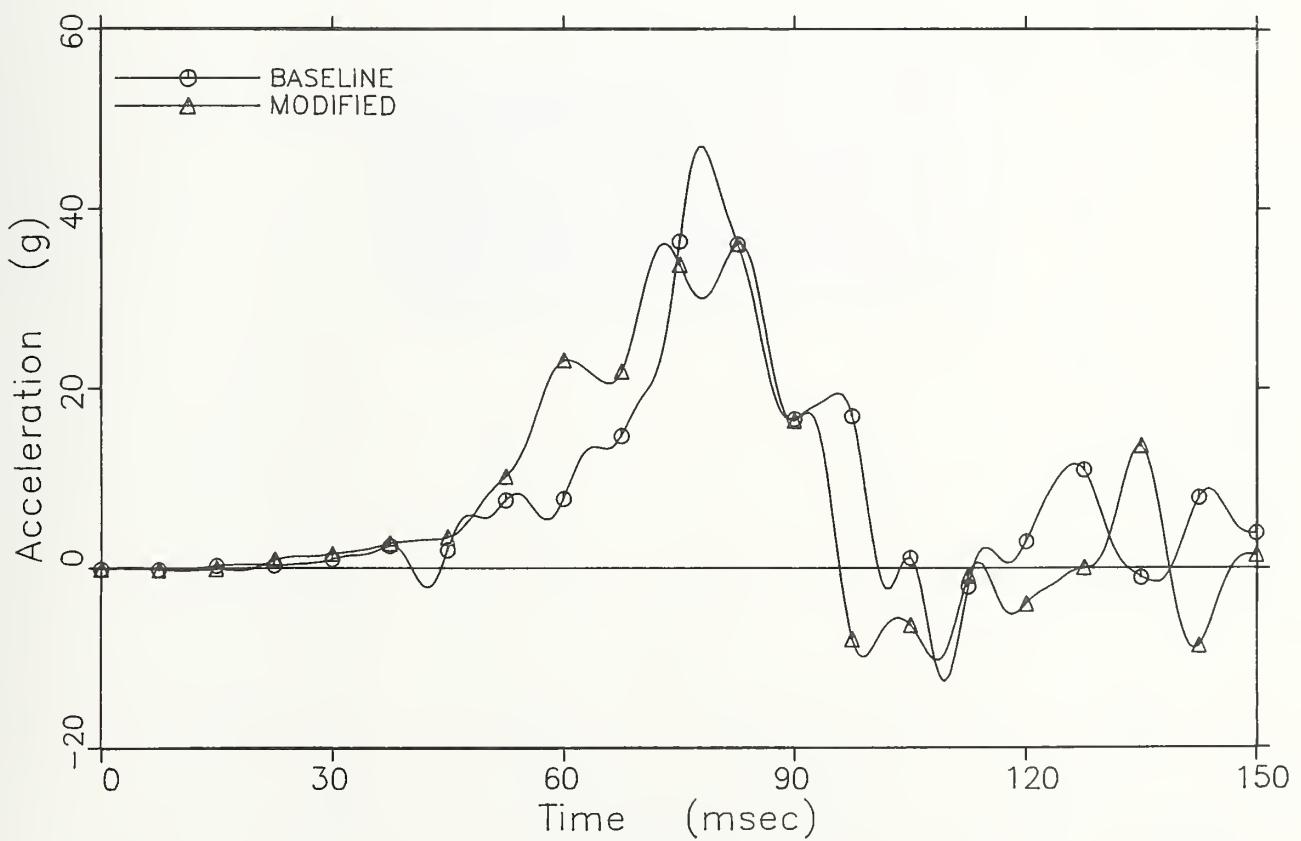


POLE TESTS - PASSENGER - LEFT LOWER RIB

FIGURE 6.4 -- Comparisons of Passenger Rib Acceleration Responses



POLE TESTS — PASSENGER — UPPER SPINE



POLE TESTS — PASSENGER — LOWER SPINE

FIGURE 6.5 -- Comparisons of Passenger Spinal Acceleration Responses

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